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Energy efficient safe SHip OPERAtion (SHOPERA)

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Abstract

The 2012 guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships, MEPC.212(63), as updated by MEPC 245(66) in April 2014, represent a major step forward in implementing energy efficiency regulations for ships through the introduction of the EEDI limits for various types of ships. There are, however, serious concerns regarding the sufficiency of propulsion power and steering devices to maintain manoeuvrability of ships in adverse conditions, hence regarding the safety of ships, if the EEDI requirements are achieved by simply reducing the installed engine power. This was the rationale for a new EU funded research project with the acronym SHOPERA (2013-2016), aiming at developing suitable methods, tools and guidelines to effectively address these concerns. The paper discusses the background of project SHOPERA and outlines the formulation of suitable criteria and methods for the assessment of ship's manoeuvrability and safety under adverse weather conditions.

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1. Introduction

The introduction of the Energy Efficiency Design Index (EEDI) was a major step towards improving energy efficiency and reducing GHG emissions of shipping; however, it has also raised concerns that some ship designers might choose to lower the installed power to achieve EEDI requirements instead of introducing innovative propulsion concepts. This can lead to insufficient propulsion and steering abilities to maintain manoeuvrability of ships under adverse weather conditions, thus to a serious ship safety problem. Work carried out by IACS highlighted this issue and led to the development of first draft guidelines for consideration by IMO in 2011 (see IMO MEPC 62/5/19 & MEPC 62/INF.21), which later resulted in *2012 Interim Guidelines* (see IMO MEPC 64/4/13 & MEPC 64/INF.7), updated in 2013 in Res. MEPC.232 (65). Even though the *2013 Interim Guidelines* prevent irrational reduction of installed power, their sufficiency was disputed, especially concerning the set-up of the minimum power lines for some ship types and sizes and the adversity of the weather conditions to be considered in the assessment and removal of comprehensive assessment. Several research initiatives in various European countries and Japan, aiming at updating the guidelines (see, e.g. IMO submissions MSC 93/21/5 and MSC 93/INF.13 by Greece, MEPC 67/INF.22 by Japan, MEPC 67/4/16 by Denmark, Japan and the Republic of Korea, and MEPC 67/INF.14 by Germany, Norway and the United Kingdom) were noted and are expected to lead to the rationalization of the interim guidelines, may be at MEPC 70 in October 2016.

To address the above challenges by in-depth research, the EU funded project SHOPERA (Energy Efficient Safe SHip OPERAtion) (2013-2016) was launched in October 2013. SHOPERA is developing suitable numerical methods and software tools and is conducting systematic case studies, which will enable the development of improved guidelines and their submission for consideration to IMO. A strong European RTD consortium was formed[1] , representing the whole spectrum of the European maritime industry, including classification societies, universities, research organisations and model basins, ship designers, shipyards and ship operators. The project's objectives are:

- Develop criteria and corresponding environmental conditions to assess sufficiency of propulsion and steering systems of ships for manoeuvrability in adverse conditions, including open sea, coastal waters & restricted areas.
- Develop and adapt existing high fidelity hydrodynamic simulation software tools for the efficient analysis of the seakeeping and manoeuvring performance of ships in complex environmental and adverse weather conditions.
- Perform seakeeping and manoeuvring model tests in seaway by using a series of prototypes of different ship types to provide the required basis for the validation of employed software tools.
- Develop simplified assessment methods, to the extent feasible, which should enable a quick assessment of the safety margins of ship designs with respect to the minimum propulsion and steering requirements for manoeuvrability in adverse weather conditions.
- Integrate validated methods and software tools for the hydrodynamic manoeuvrability assessment of ships in adverse weather conditions into a ship design software platform and combine it with a multi-objective optimization procedure, which is targeting sufficient propulsion and steering requirements for safe ship operation in adverse weather conditions, while keeping the right balance between ship economy, efficiency and safety of ship and the environment.

[1] http://www.shopera.org, National Technical University of Athens (NTUA, coordinator), DNV-GL, Lloyds Register (LR), Marintek (MRTK), Instituto Superior Tecnico (IST), Univ. Duisburg-Essen (UDE), Registro Italiano (RINA), Flensburg Schiffbau Gesellschaft (FSG), Uljanik Shipyard (ULJ), VTT, Flanders Hydraulics Research (EVFH), CEHIPAR, Strathclyde University (SU), Denmark Technical University (DTU), Tech. Univ. Berlin (TUB), Delft University of Technology (DUT), Naval Architecture Progress (NAP), Danaos Shipping Company Ltd. (DANAOS), FOINIKAS Shipping Co., CALMAC Ferries Ltd.

- Conduct investigations on the impact of the proposed new guidelines for the minimum propulsion and steering efficiency for manoeuvrability in adverse conditions on the design and operational characteristics of various ship types by design teams comprising designers, shipyards, shipowners, classification societies, research institutes and universities. The impact on EEDI will be investigated in parallel by implementation of the developed holistic optimisation procedure in a series of case studies.

2. Present status

2.1. Review of existing regulations and proposals

Ship's manoeuvrability is presently addressed by the IMO Standards for Ship Manoeuvrability, adopted in 2002 (see IMO Res. MSC. 137(76)), which address turning ability, initial turning ability, yaw-checking ability, course-keeping ability and emergence stopping ability, which are evaluated in simple manoeuvres in calm water. These Standards have been often criticized for not addressing ship's manoeuvring characteristics at low speed, nor in restricted areas and in adverse weather conditions.

Work by the IACS Project Teams PT4-PT7 on minimum power requirements for manoeuvrability in adverse weather conditions within the EEDI regulations started with an analysis of functional requirements to manoeuvrability in the open sea and coastal areas (IMO MEPC 62/5/19, MEPC 62/INF.21) and *concluded that manoeuvring in coastal waters is more challenging than in the open sea*; the resulting criteria for ship propulsion and steering abilities were formulated in IMO MEPC 64/4/13 and MEPC 64/INF.7: the ship should be able to (1) *keep course in waves and wind from any direction* and (2) *keep advance speed of at least 4.0 knots in waves and wind from any direction*. The corresponding weather conditions are not very severe (*even though appreciably high, when considering coastal waters*), because in practice ship masters used not to stay near the coast in an increasing storm and either search for a shelter or leave to the open sea, where they take a position with enough room for drifting. The recommended environmental conditions (wind speed of 15.7 m/s at significant wave height of 4.0 m for ships with L_{pp}=200 m, to 19.0 m/s and 5.5 m, respectively, for L_{pp}=250 m and greater) were derived by benchmarking of tankers, bulk carriers and container ships in the EEDI database against the above two criteria (1)-(2). The minimum required advance speed 4.0 knots is assumed to provide some minimum speed over ground for timely escape of the coastal area, and include some margin to take into account possible current.

2.2. Typical accidents and statistical analysis

Few available detailed accident investigations (see, e.g. Shigunov & Papanikolaou, 2014) have identified as the most frequent cause for grounding accidents in an increasing storm, the scenario of a ship waiting at anchor until it starts dragging, while we have a delayed attempt to escape or too low rating of the engine. In several accidents, however, (see e.g. MAIB reports 2009a, 1996, 2012a, ATSB 2008), vessels were anyway not able to move away from the coast or turn into the waves and wind despite full engine power applied. In the accident (MAIB 2009a), full engine power was not available due to failure of one of engines; in the accident (MAIB 1996), forward speed had to be reduced to wait for entrance clearance in a port approach channel; whereas in the accidents (MAIB 2012a) and (ATSB 2008), full engine power was available and applied. Such accidents suggest that there is a minimum limit for the propulsion and steering abilities for a ship to be able to leave the coastal area in an increasing storm. Table 1 shows a summary of relevant criteria and weather conditions from several accident reports.

Table 1. Summary of accident reports.

Ref.	Relevant criteria	Environmental Conditions
MAIB 2002	Propulsion	Bf 5-7, low waves
MAIB 2009b	Propulsion	Bf 10
MAIB 2012b	Course-changing	v_w 38-45 knots
MAIB 2009a	Course-changing	Bf 9-10, h_s > 10 m
MAIB 1996	Course-changing	gale force wind, low waves
MAIB 2012a	Propulsion	v_w 40 knots, h_{max} = 4 m
ATSB 2008	Propulsion	v_w 38-46 knots, h_s = 6.0-6.6 m

Regarding other type of accidents and their relation to adverse weather conditions, we may recall the well-known statistics of the HARDER project indicating that more than 80% of *collision accidents* happened at significant wave height below 1.5 m (thus practically, for large ships, in calm water conditions), whereas significant wave heights exceeding 4 m were practically not recorded.

Similar results were obtained from a comprehensive statistical analysis of more recent ship accidents[2] in adverse sea conditions, which was conducted in SHOPERA by Ventikos et al (2014). Two main sources were used for the collection of the necessary information, namely the IHS Sea-Web marine casualty database and the public area of the marine casualties and incidents database of the International Maritime Organization (IMO) Global Integrated Shipping Information System (GISIS). The information collected from these sources was cross-checked, wherever possible, with accident reports acquired from other sources (various National Maritime Safety authorities). A characteristic sample of results of this analysis is given in Figures 1 and 2. From these statistics it is evident that the most vulnerable ship types with respect to navigational accidents in adverse conditions are general cargo ships, followed by Ro-Ro ferries, bulk carriers and tankers (Figure 1). For these ship types, the accident location varies between *port areas* (almost exclusively for the Ro-Ro ferries) and generally *limited waters areas* (port and restricted waters) for the general cargo and bulkers; for tankers, we observe some increased sensitivity in *en route* (open seas) conditions. Among the three navigational accident types, *groundings* exhibit the highest rates for cargo carrying ships (*general cargo, bulkcarriers, tankers*), whereas for *Ro-Ro ships contacts* are associated to the highest rates.

Based on the available information, hull damage was selected as the main consequence of accidents in a conducted comprehesive risk analysis. The collected data were organized in categories of increasing level of severity, considering their qualitative nature. The calculated accident rates, which are related to the Fleet at Risk, are in the range of 10^{-5} to 10^{-3} accidents per ship per year. They are by one order of magnitude lower than accident rates calculated in Formal Safety Assessments, which do not consider the prevailing weather conditions. Overall, it shows that *groundings and contacts in heavy weather conditions are the accident types with the highest risk values across all ship types*. The comparison of risk levels between ship types yielded the following results: First, *Ro-Ro Ferries and Cargo ships* exhibit high risk values due to *high accident frequency and medium level of consequences*; and second, *Gas Carriers, Tankers and Bulk Carriers* exhibit high risk values due to the observed *high level of accident consequences*.

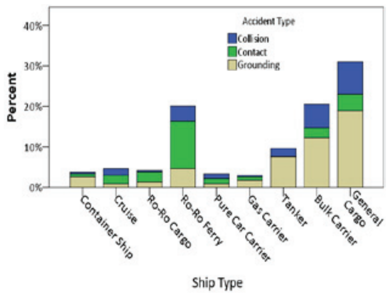


Fig. 1. Percentage of ship types involved in navigational accidents under adverse weather conditions.

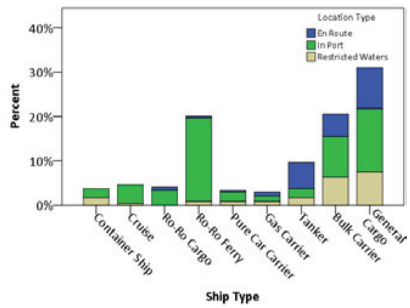


Fig. 2. Percentage of ship types engaged in navigational accidents under adverse weather conditions by accident location.

3. Manoeuvrability criteria and environmental conditions

The above considerations suggest that steering and propulsion abilities of ships are challenged by the environment in very different ways in three distinct situations, each of which requires specific criteria, see Shigunov&Papanikolaou (2014): manoeuvring in the open sea, manoeuvring in coastal waters, and low-speed manoeuvring in restricted areas.

[2] Accident period 1980-2013; ships over 400GT built after 1980; accidents related to adverse and heavy weather conditions, excluding poor visibility (e.g. fog).

3.1. Manoeuvring in open sea

In the open sea, a fundamental functional requirement is the ability of ship *to change the heading into a favourable one with respect to the environment and to keep this heading*. Noting that the ability to maintain heading should supersede the ability to change heading, the following possible requirement was proposed in Shigunov & Papanikolaou (2014) as a practical, easy to evaluate criterion:

- (C1) *the ship should be able to keep heading in head to bow-quartering seaway up to 60 º off-bow*.

3.2. Manoeuvring in coastal areas

Operation in coastal areas places greater demand on manoeuvrability than operating in the open sea: the ship may require *to perform, in principle, any manoeuvre (as well as maintain the required course), and also maintain some speed over ground* to enable leaving coastal area before the storm escalates. Noting that if a ship can keep any course with respect to seaway, including courses most unfavourable for course-keeping, than the ship will also be able to perform any course change, the following two practical criteria can be proposed (Shigunov & Papanikolaou , 2014): *In waves and wind from any direction, the ship should be able to*

- (C2) keep a prescribed course and
- (C3) *keep a prescribed minimum advance speed*.

These criteria were the background of the Level 3 (Comprehensive Assessment) of the *2012 Guidelines* (IMO MEPC 64/4/13, MEPC 64/INF.7, MSC-MEPC.2/Circ.11); the required minimum advance speed was defined there as 4 knots to provide, first, sufficient time for leaving coastal area and, second, some margin for a current. Level 3 was removed from *2013 Interim Guidelines* (IMO Res. MEPC. 232.65), which, however, still contain Level 2 (Simplified Assessment), which was empirically derived from the application of Level 3 to several container ships, bulk carriers and tankers (IMO MEPC 64/INF.7).

3.3. Low-speed manoeuvrability in restricted areas

Manoeuvrability at low forward speed in strong wind and, perhaps, current, is relevant for ships with large windage area during approaching to and entering ports. The speed is limited because of navigational restrictions, thus rudder efficiency is reduced. Note that such criteria may lead to enhanced requirements to steering devices, but will not impose any restrictions on minimum propulsion power. As practical criteria, Shigunov & Papanikolaou (2014) propose *Course-keeping at a specified low speed in strong wind in*

- (C4) *shallow water,*
- (C5) *shallow water near a bank and*
- (C6) *shallow water during overtaking by a quicker ship*.

4. Evaluation of criteria

Compliance with the *IMO Manoeuvrability Standards* (IMO Res. MSC.137.76) is commonly verified by full-scale trials in calm water; full-scale trials are however impracticable when considering adverse weather conditions. Alternatives are model tests and numerical computations. For the sake of practicality, the assessment procedure should be flexible, i.e. it should allow for alternative assessment ways (model tests, numerical methods, empirical formulae or combination of these methods) depending on designer needs and particular project. For example, it should facilitate using high-fidelity assessment methods (model tests or accurate numerical methods), when it is necessary or advantageous for the ship designer or owner, while it should allow using simple methods otherwise. As a part of regulations, such procedure should be verifiable, i.e. allow combining results from model tests, numerical computations and empirical formulae in such a way that any result can be verified or replaced, if necessary, during design or approval. This is possible if the procedure is modular, and each module is based on simple computations or simple experiments in well-controlled conditions. Finally, the procedure should facilitate the use of state-of-the art technology available in the industry: on the one hand, it should be as accurate as practicable with the available technology, inexpensive and readily available for application by any shipyard and administration, and, on the other hand, the procedure should be able to accommodate any new knowledge, which will be generated due to innovation efforts, without the need to revise the procedure.

The assessment procedure proposed here is based on *neglecting oscillatory forces and moments* and thus considers only time-average forces, moments and other variables (propeller thrust, torque and rotation rate, required and available power, drift and rudder angles, etc.), because time scale of these oscillations is shorter than time scale of manoeuvring motions. Neglecting oscillatory forces and moments reduces the evaluation of criteria (C1)-(C6), introduced above, to a solution of a set of *steady coupled equilibrium equations* in the horizontal plane under the action of time-average wave-induced forces and moments, wind forces and moments, calm-water forces and moments, including interaction effects, rudder forces and propeller thrust (see, Papanikolaou et al., 2015)

Figure 3 shows examples of application of this procedure, which is based on the manoeuvring criteria C2 and C3 and is presenting the operability of the ship in polar coordinates, with ship speed (radial coordinate) and seaway direction (circumferential coordinate, head waves and wind come from the top). Line A corresponds to situations when required delivered power P_D is equal to the available delivered power P_D^{av}, line B corresponds to the minimum advance speed (here 4 knots), and line C limits the dark area, where the required rudder angle for course-keeping exceeds maximum rudder angle (here 25 º). The left plot corresponds to a ship in seaway when the installed power is sufficient to fulfill both criteria C2 and C3 (line A does not cross lines B and C); in the middle, the situation is shown when the minimum required installed power is defined by required minimum advance speed in head seaway (line A crosses line B); and in the right plot, the minimum required installed power is defined by course-keeping in beam seaway (line A crosses line C).

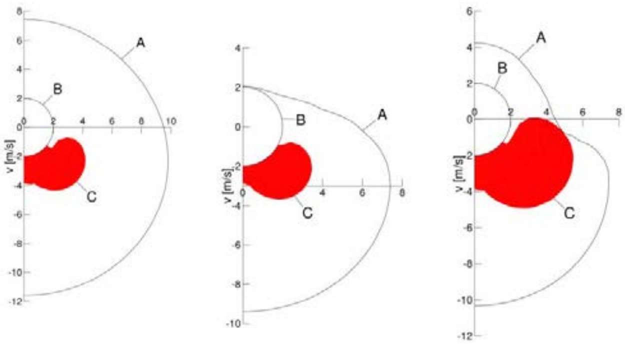


Fig. 3. Examples of assessment results: lines "required power equal to available power" (A), "advance speed 4.0 knots" (B) and "rudder angle 25 º" (C) for situations with sufficient installed power (left); power defined by advance speed in head seaway (middle) and power defined by steering ability in beam seaway (right).

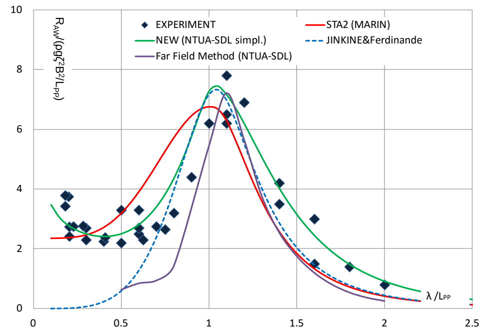


Fig. 4. Time-average wave-induced force X_d or added resistance for standard KVLCC2 tanker in head waves by various methods, Fn=0.142 (Liu & Papanikolaou, 2015).

The advantage of the proposed approach is that the time-average forces and moments due to wind, waves, calm water, rudder and propeller can be computed or measured separately, using most convenient method (model tests, numerical computations or empirical formulae). If model tests or numerical computations are used for some of contributions, they are defined in stationary setups under well-controlled conditions, and then combined in the simple steady model. Moreover, even if simplified methods (e.g. empirical formulae) are chosen for some or all contributions, the entire formulation still remains physically meaningful.

5. Modeling and employed methods

5.1. Potential flow methods

Several developments in the above described methods are presently being made in parallel by various SHOPERA partners and thus only some typical results are herein presented; nevertheless, an overview of the work in progress is given. The 3D seakeeping code HYBRID of NTUA is being further developed for simulating the 6 DoF nonlinear ship motions in adverse sea states and for studying the parametric rolling problem. The HYBRID code has been applied to the study of parametric rolling problem of the ITTC-A1 ship and the calculation of drift forces and added resistance of RoPAX, KVLCC2, and DTC ships. The HYBRID code is essentially a nonlinear time domain method based on the impulse response function concept and incorporates the nonlinear Froude-Krylov force and hydrostatic force to simulate the six DoF ship motions. For the calculation of drift forces and added resistance, a far-field method and a proper semi-empirical formula for short wave region correction are used (Fig. 4) (Liu & Papanikolaou, 2015).

5.2. Field methods

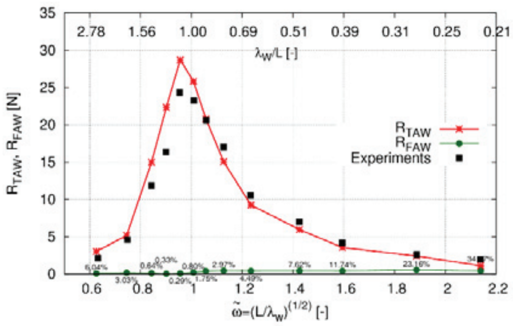
Several simulations were performed for different ships in waves using the RANS solver OpenFOAM. Wave drift forces were computed for different heading angles and compared with available experimental data. Ships under investigation were the Wigley III hull, the Duisburg Test Case (DTC) containership, described by el Moctar et al. (2012) and a cruise vessel. During these studies, influencing parameters such as discretization, numerical setups and modes of motion were investigated. Achievements have been obtained with respect to the following aspects: grid and convergence study, preliminary validation study for the calculation of second order wave forces and comparison between fixed and spring constrained surge motions on added resistance (Ley et al., 2014). The final objective is developing off-line databases for second order wave forces, approximations of manoeuvring forces in shallow water, rudder forces behind the propeller in waves, a simplified unsteady model for a screw propeller and characteristics of hull-propeller interaction in waves, studied with a RANS solver.

The RANS code Neptuno (Cura Hochbaum & Voigt, 2002) has been enhanced with a new body force propeller model, allowing a better approximation of the rudder inflow and propeller torque. The code will be used to calculate forces on the hull due to waves, current and wind to derive a coefficient set including these environmental effects. The new body force model is based on a large set of RANS calculations for the isolated propeller rotating in homogenous inflow. The present calculations were made for a stock propeller with six blades, seen in Fig. 5(a). The advance coefficient J and the angle of incidence α were varied in a range of 0.1 to 0.9 and 0 º to 30 º, respectively. For each time step of the calculated case – which corresponds to a specific rotation angle of a considered propeller blade – the resulting pressure and shear stresses in each cell of a triangular grid on both the suction and pressure side of the blade are saved. The propeller disk is then discretized with a polar grid (Fig. 5b) and for each cell of this grid, the three components of the mean force per unit area caused by all propeller blades over a complete revolution are calculated and stored in a database for each considered pair J and α. In addition, the corresponding induced velocities of the propeller in an upstream reference plane are saved as well. When setting up the RANS calculation of a forced motion test, each cell of the polar grid on the propeller disk gets mapped to a cell in the computational domain and vice versa. The individual inflow condition at this cell is then evaluated from the total local wake field.

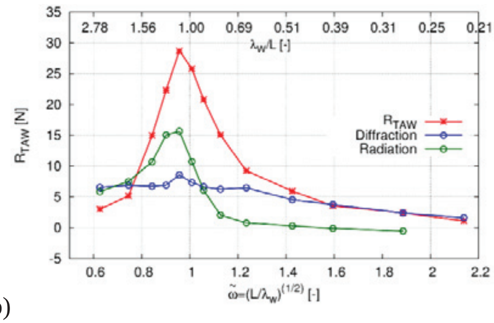
(a) (b)

Fig. 5. Pressure on blades during RANS calculation and mean axial force distribution on propeller disk (code NEPTUNO, Cura Hochbaum & Voigt, 2002).

Figure 6 (a) shows computed and measured added resistance in regular waves for F_n=0.23. The computations were performed using a Reynolds-averaged Navier Stokes (RANS) equations solver. Numerical results agreed fairly well with model test measurements. Figure 6 (a) shows the percentage of the total added resistance R_{TAW} attributed to friction effects R_{FAW}, which is monotonously increasing with increasing wave frequency. Figure 6 (b) shows the components of the added resistance related to radiation and diffraction effects. To determine the diffraction part, simulations were conducted in waves with the ship totally restrained at its dynamic equilibrium sinkage and trim position. To compute the radiation part, simulations were performed in calm water with the ship executing forced heave and pitch motions. As expected, the radiation component is the predominant part of total resistance in waves at λ/L ratios from about 0.8 to 1.1, whereas in short wave radiation effects die out. In longer waves, radiation and diffraction components are nearly equal. It should be noted that the sum of radiation and diffraction force components does not yield the total resistance, because of the interaction effects between radiation and diffraction, which are herein not shown separately, see Ley et. al. (2014).



(a)



(b)

Fig. 6. Computed and measured added resistance in waves for the DTC containership at Fn=0.23 from Ley et.al. (2014). RTAW denotes the total added resistance, RFAW the frictional added resistance L the ship length between perpendiculars, and λ_w wave length.

6. Experimental studies

Within the framework of SHOPERA, a comprehensive test program consisting of more than 1,300 different model tests for three ship hulls of different geometry and hydrodynamic characteristics has been conducted by the involved partners MARINTEK, CEHIPAR, Technische Universität Berlin and Flanders Hydraulics Research. The hull types encompass two standardized, public domain designs, namely the KVLCC2 tanker (KRISO VLCC, developed by KRISO) and the DTC container ship (Duisburg Test Case, developed by Universität Duisburg-Essen) as well as a RoPax ferry design, which is a proprietary hull design of a member of the SHOPERA consortium.

The broad test matrix of unconventional tests establishes a database of relevant experimental results beyond the state-of-the-art to validate the various methods and software tools that are being developed and refined within the framework of SHOPERA. Added resistance, drift force and propulsion tests have been performed in high and steep regular and irregular waves to ensure the applicability of hydrodynamic numerical model to adverse wave conditions. Experimental data have also been collected for manoeuvring in waves: at MARINTEK, rudder force measurements, turning circle and zig-zag tests have been performed with the DTC in waves.

In Figure 7, an overview of turning circles tests is shown. The influence of wave period and the initial heading on the trajectory is shown. Turning circle in calm water requires more space than turning circles performed in head waves. The head waves push against the bow and thus amplify the effect of the moment produced by the rudder, whereas the yaw wave moment, acting against the rudder moment when the ship is turning from 180 ° to 270 °, leads to oblique drift in the direction of wave propagation. In following sea conditions, the advance and tactical diameter increase compared to head sea conditions, but the manoeuvres require less space than in calm water. In this situation, the wave moment amplifies the effect of the rudder moment when the ship is turning from 180 to 270 °, leading to a distorted trajectory with pronounced drift between consecutive turns.

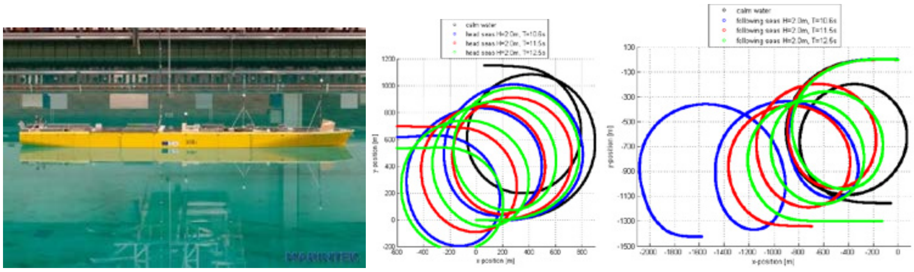


Fig. 7. Free running self-propelled DTC model tests in MARINTEK's Ocean Basin (left); comparison of DTC trajectories for turning circle manoeuvres in calm water and regular head (center) and following (right) waves.

7. Conclusions

The problem in hand is very demanding, both from the scientific and the practical/regulatory point of view. So far developments in SHOPERA lead to the following main conclusions:

- The most vulnerable ship types with respect to navigational accidents in adverse conditions are general cargo ships, followed by Ro-Ro ferries, bulkers and tankers. For the above ship types, the accident location varies *between* port areas (almost exclusively for the Ro-Ro ferries) and generally limited water areas (port and restricted waters) for the general cargo ships and bulkers; for tankers, we observe some increased sensitivity in en route conditions.
- <u>Proposed criteria and practical assessment procedure</u> correspond in general to the knowledge and technology presently available in the industry; however, their implementation in the practical design and approval procedure require additional adaptation effort.
- <u>Development and validation of numerical methods:</u> high-level methods (time-average wave forces and moment at *forward* speed) and empirical formulae for simplified methods (calm-water reactions, including shallow-water and interaction effects; rudder forces in propeller race; and time-average wave forces and moment).

The level of severeness/adverseness of the environmental conditions, especially of seaway, is debatable and, if left upwards open, may lead to severe impacts on other ship properties left until now outside of the current discussion (see disputable submission IMO-MSC 93/21/5 and commentary IMO MEPC 67/4/16). One may remember heated discussions in the maritime community about design, operational and regulatory measures after the loss of the bulk carrier MV Derbyshire in abnormal sea conditions due to typhoon Orchid in 1980. It appears that the agreement on rational assessment criteria, to which the severeness of the environmental conditions belong, is of paramount importance and the most important to be settled. Following this and the establishment of suitable assessment methods, which is a nontrivial task, it is up to the ship designers to manage effectively possible contradictions between the EEDI and minimum propulsion and steering requirements for manoeuvrability in adverse conditions, which will have to consider common navigational practice. Thus, an important task is to elaborate on optimal design solutions, to demonstrate their practical feasibility and then to assess them through case studies involving multiple design and operational criteria.

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